Spatiotemporal variability of snow properties derived from AVIRIS

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Jet Propulsion Laboratory
California Institute of Technology

Case study of spatial and temporal variability of snow cover, grain size, albedo and radiative forcing in the Sierra Nevada and Rocky Mountain snowpack derived from imaging spectroscopy

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Sierra Nevada Study Area
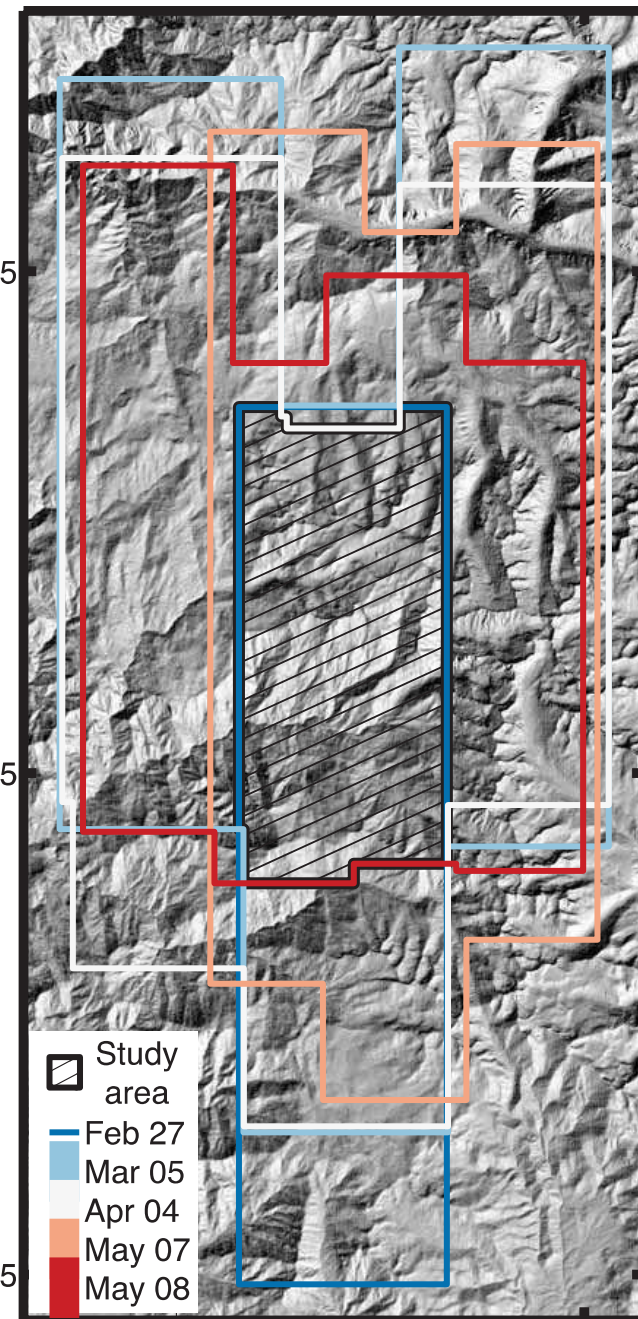
Kings and Kaweah river basins

Sierra Nevada, CA. 2009

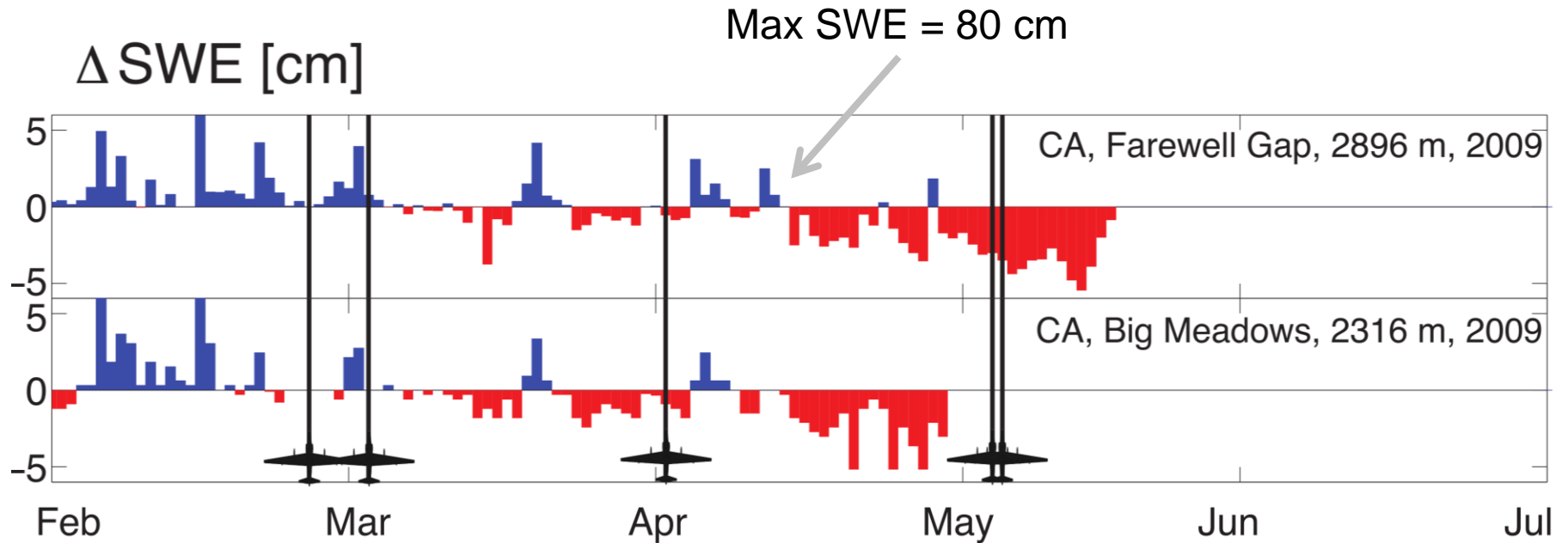|	
Dates	27 Feb., 05 Mar., 04 Apr., 07 May, 08 May
Pixel Size [m]	14.5
Image Area [km^2, pixels]	$252.03067, 1.2 \cdot 10^6$
Elevation Min./Mean/Max. [m]	1140 / 2575 / 3533

California
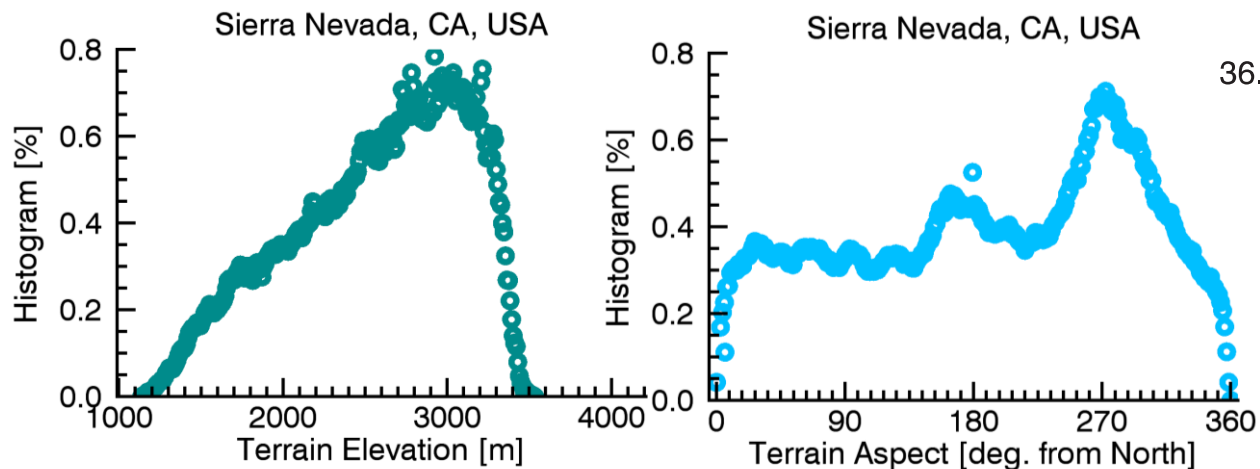
Snow Hydrology

Sierra Nevada study site

- Maritime snowpack (typically warmer and deeper than continental)

- 2009 was an average snow year in the Sierra Nevada

Retrieval Algorithms

Directional reflectance

$$HDRF_{sfc}^{obs} = \frac{R_{sensor}^{obs} - R_{atm}^{mdl}}{T^{\updownarrow,mdl} + S_{sfc}^{mdl}\left(R_{sensor}^{obs} - R_{atm}^{mdl}\right)}.$$

More information:

Painter, T. H., Seidel, F. C., Bryant, A. C., McKenzie Skiles, S., and Rittger, K.: Imaging spectroscopy of albedo and radiative forcing by light-absorbing impurities in mountain snow, *Journal of Geophysical Research: Atmospheres*, 118, 9511–9523, doi:10.1002/jgrd.50520, 2013.

Retrieval Algorithms

Directional reflectance

$$HDRF_{sfc}^{obs} = \frac{R_{sensor}^{obs} - R_{atm}^{mdl}}{T^{\updownarrow,mdl} + S_{sfc}^{mdl}\left(R_{sensor}^{obs} - R_{atm}^{mdl}\right)}.$$

Snow grain size

$$r : \left[\min \sum_{i=1.17~\mu\mathsf{m}}^{1.27~\mu\mathsf{m}} \left| HDRF_{snow}^{mdl}\left(\theta_\odot, \theta_v, \varphi; r; \lambda_i\right) - HDRF_{snow}^{obs}\left(\theta_\odot, \theta_v, \varphi; r; \lambda_i\right)\right|\right].$$
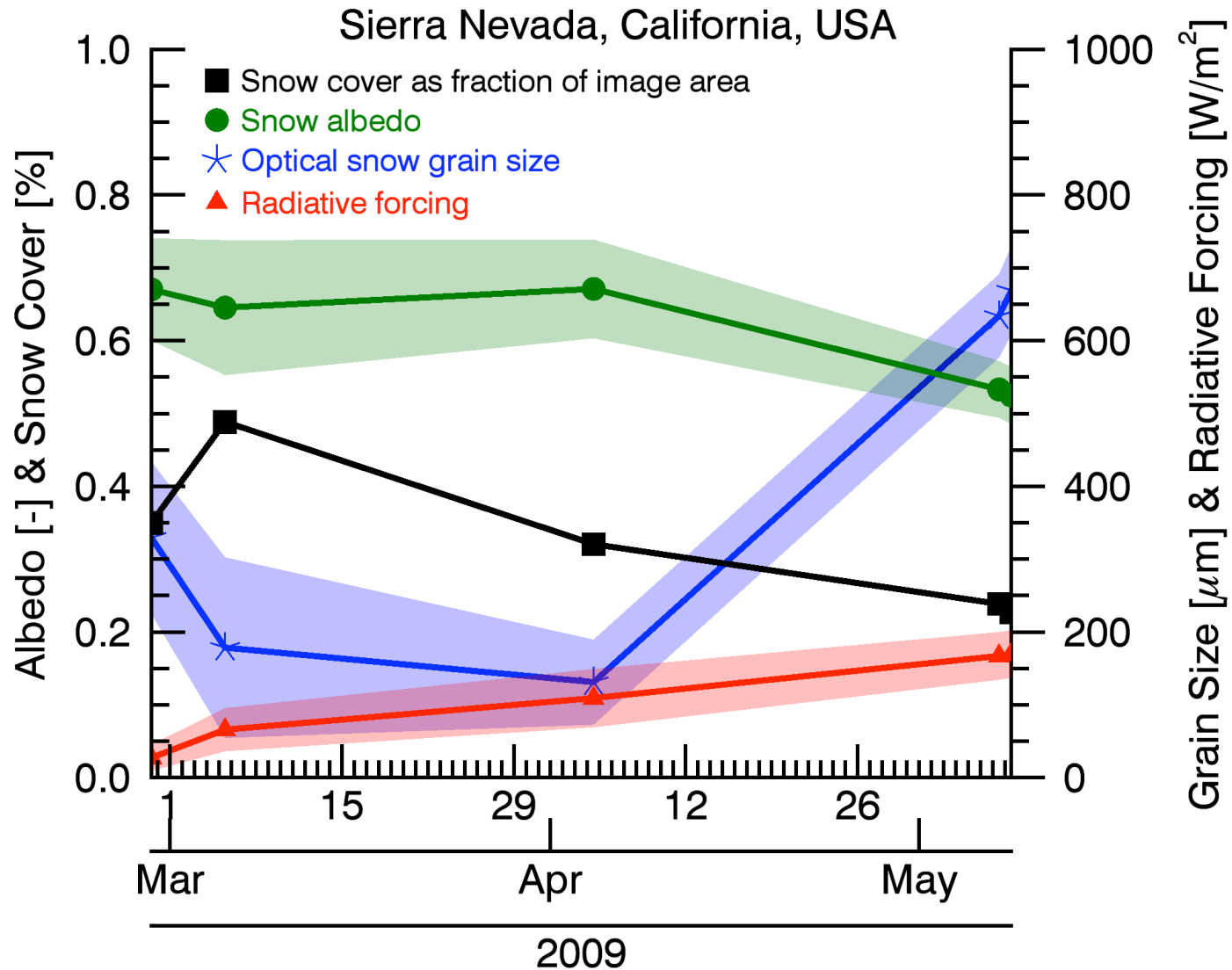
Retrieval Algorithms

Directional reflectance

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Snow albedo

$$\alpha_{snow}^{obs}(r, \lambda) = \frac{HDRF_{snow}^{obs}\left(\theta_\odot, \theta_v, \varphi; r; \lambda\right)\alpha_{snow}^{mdl}(r, \lambda)}{HDRF_{snow}^{mdl}\left(\theta_\odot, \theta_v, \varphi; r; \lambda\right)}$$

Retrieval Algorithms

Directional reflectance

$$HDRF_{sfc}^{obs} = \frac{R_{sensor}^{obs} - R_{atm}^{mdl}}{T^{\updownarrow,mdl} + S_{sfc}^{mdl}\left(R_{sensor}^{obs} - R_{atm}^{mdl}\right)}.$$

Snow grain size

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Snow albedo

$$\alpha_{snow}^{obs}(r, \lambda) = \frac{HDRF_{snow}^{obs}\left(\theta_\odot, \theta_v, \varphi; r; \lambda\right) \alpha_{snow}^{mdl}(r, \lambda)}{HDRF_{snow}^{mdl}\left(\theta_\odot, \theta_v, \varphi; r; \lambda\right)}$$

Snow radiative forcing by light absorbing impurities

$$RF_{snow} = \int_{\lambda=0.36\ \mu m}^{1.08\ \mu m} E_{sfc}^{mdl}\left(\lambda, \theta_\odot\right) \left[\alpha_{snow}^{mdl}(r, \lambda) - \alpha_{snow}^{obs}(r, \lambda)\, c(r, \lambda_c)\right] \Delta\lambda,$$

Time Series of Area Mean Values

Sierra Nevada, California, USA

Legend:
- ■ Snow cover as fraction of image area
- ● Snow albedo
- ✳ Optical snow grain size
- ▲ Radiative forcing

Left axis: Albedo [-] & Snow Cover [%] (0.0 to 1.0)
Right axis: Grain Size [μm] & Radiative Forcing [W/m²] (0 to 1000)
X axis: Mar, Apr, May — 2009

Snow Grain Size

27.Feb. 2009   04.Apr. 2009   08.May. 2009

Sierra Nevada, California, USA

Grain Size [μm]
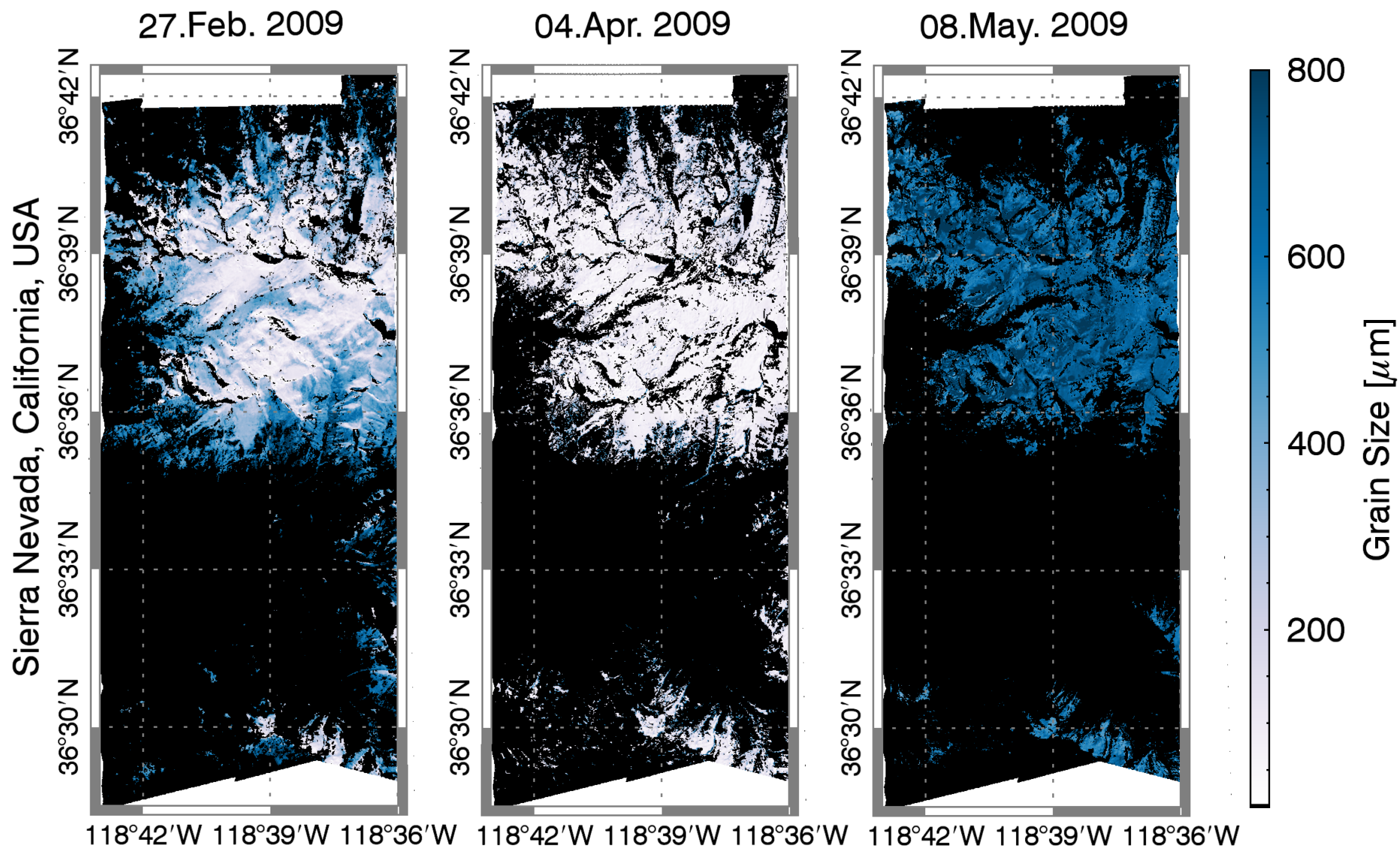
Albedo

27.Feb. 2009   04.Apr. 2009   08.May. 2009

Sierra Nevada, California, USA

Albedo [-]
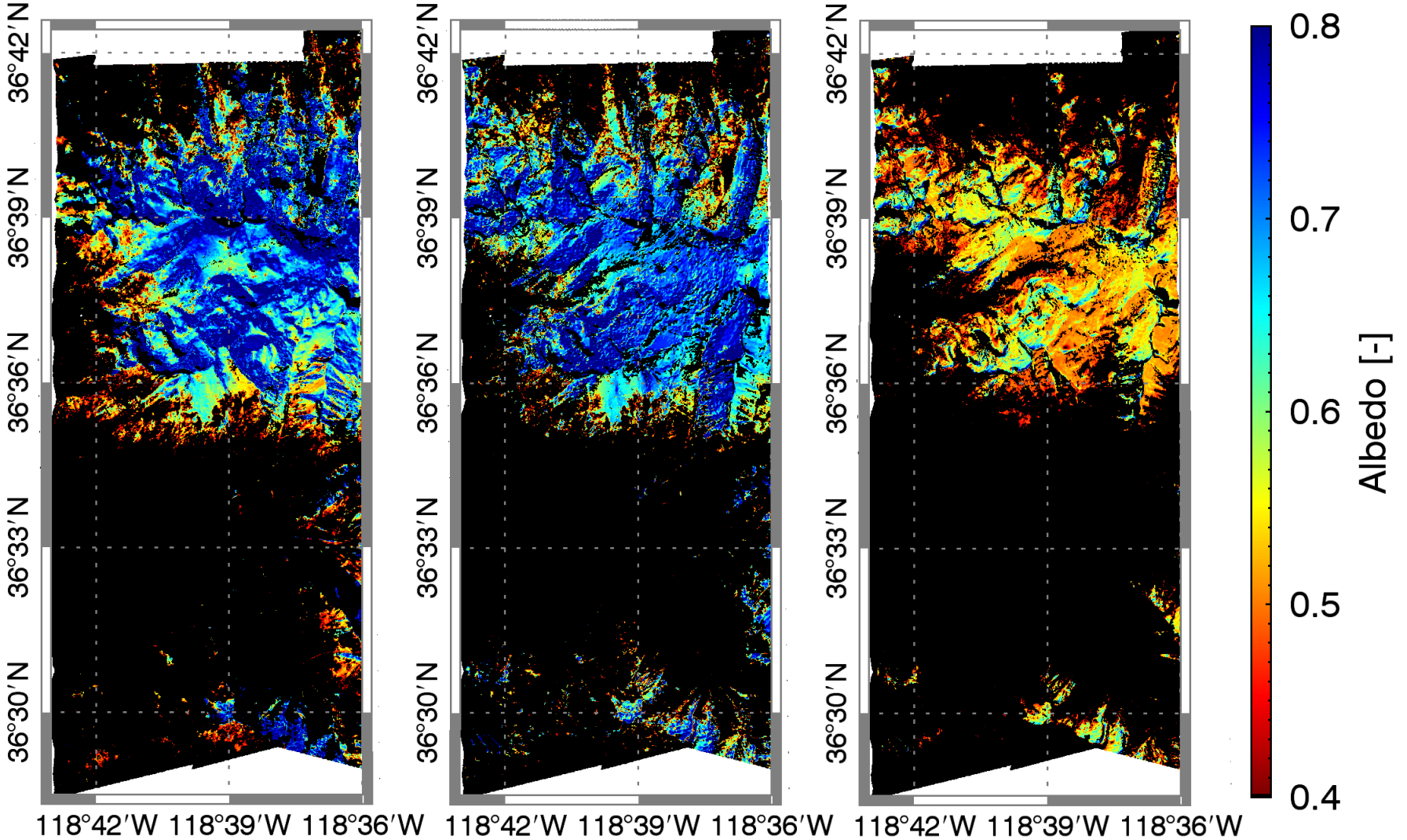
Radiative Forcing

27.Feb. 2009   04.Apr. 2009   08.May. 2009
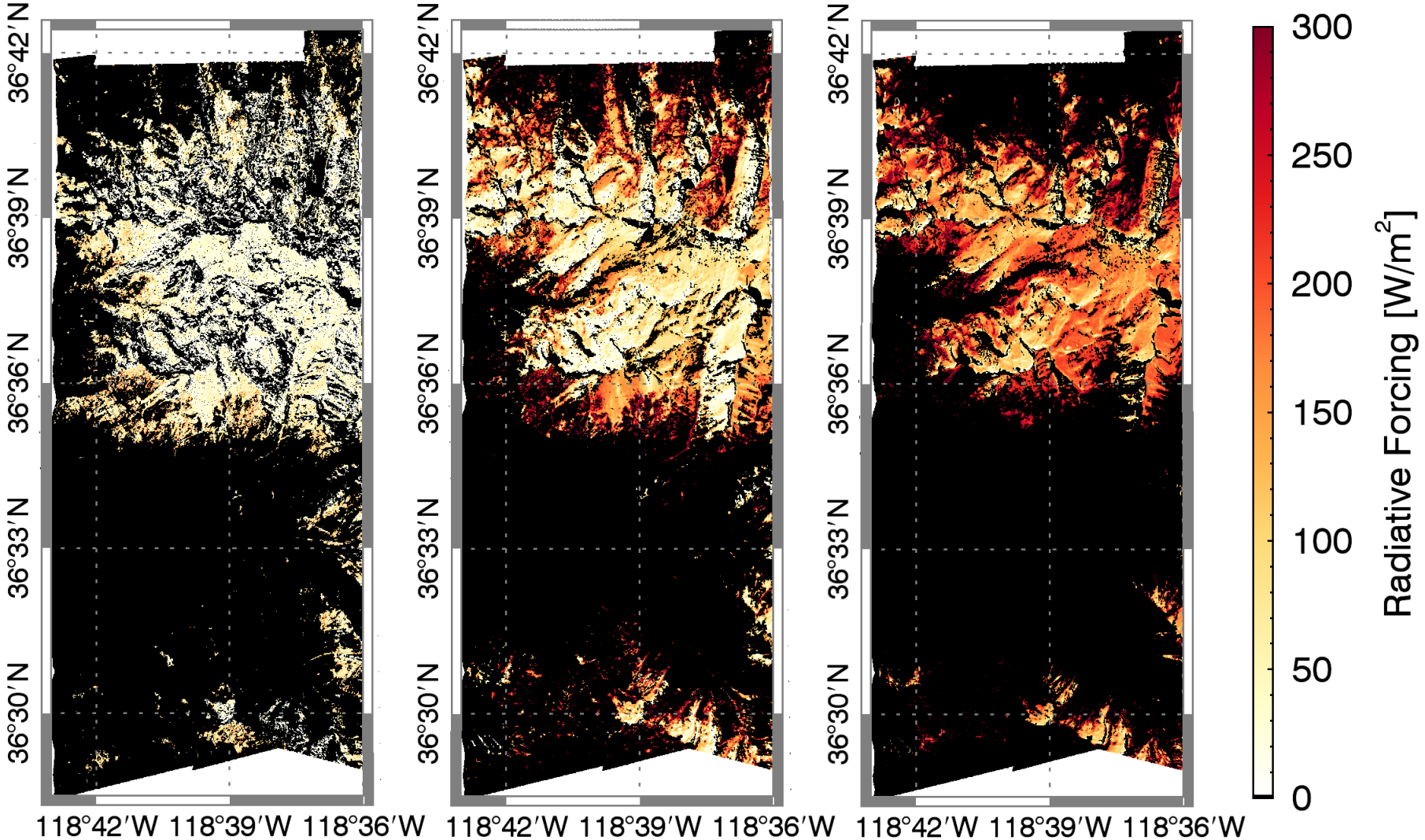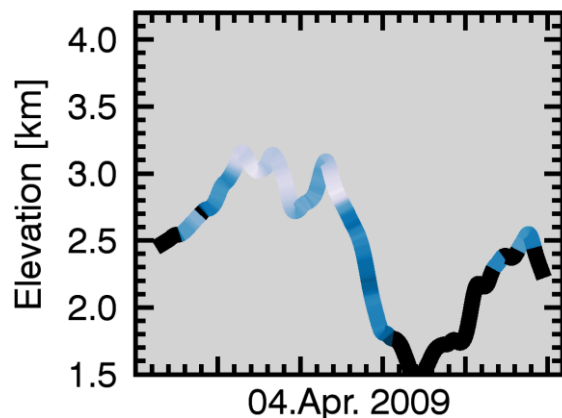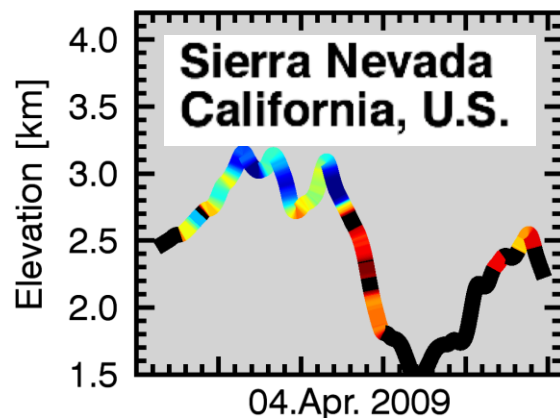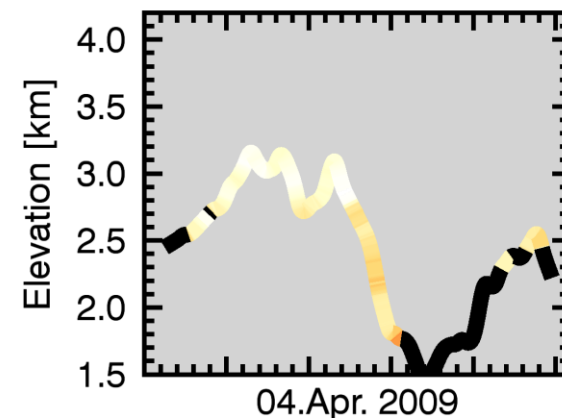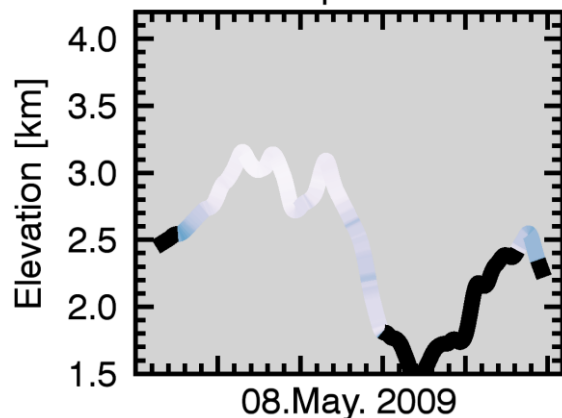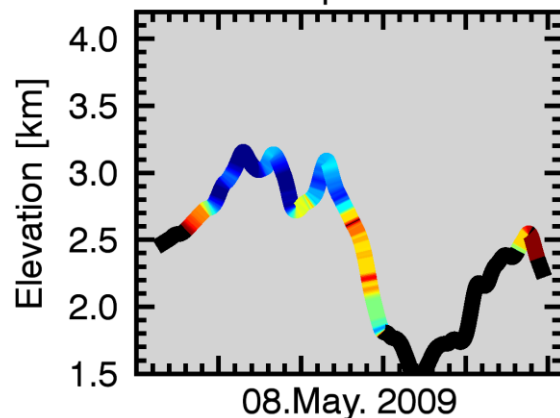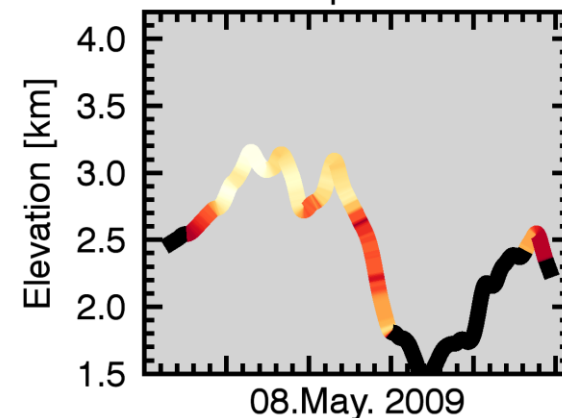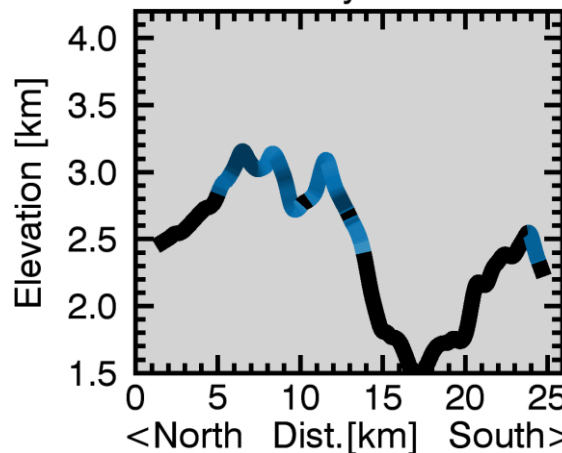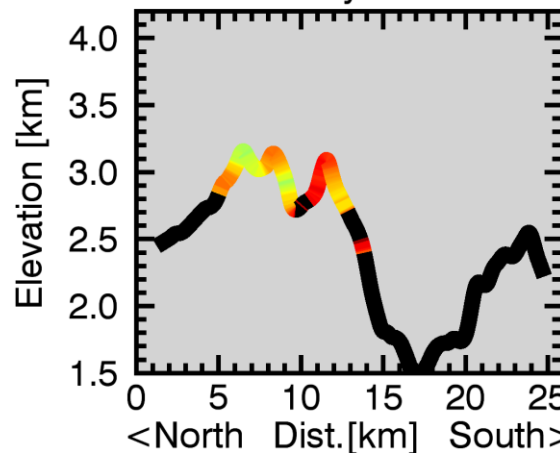
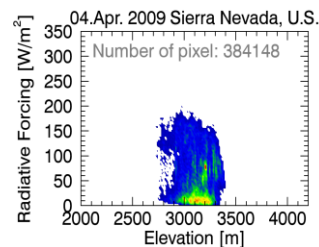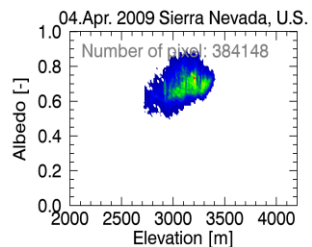Sierra Nevada, California, USA
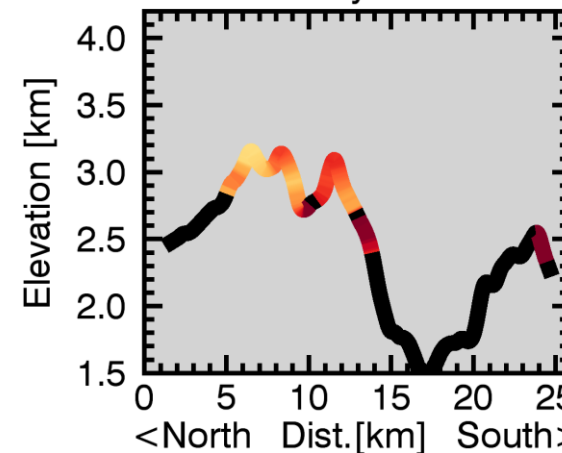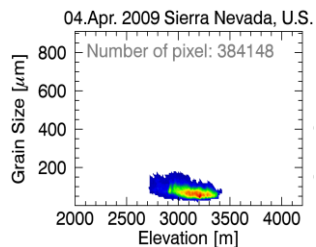
Radiative Forcing [W/m^2]

Sierra Nevada
California, U.S.

Grain Size, Albedo, and Radiative Forcing v.s. Elevation
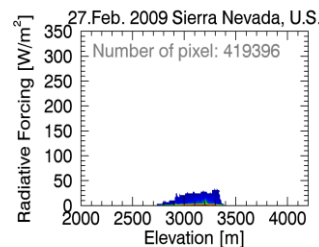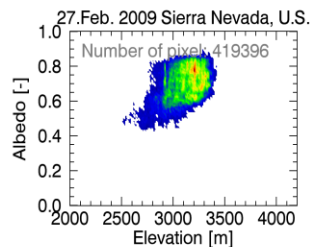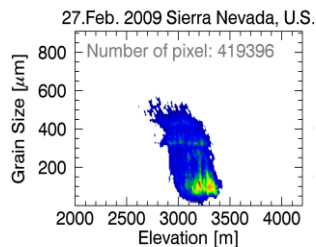
27 Feb 2009
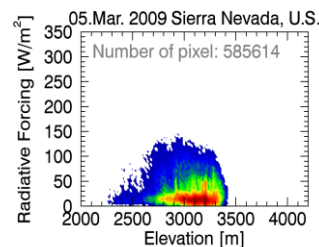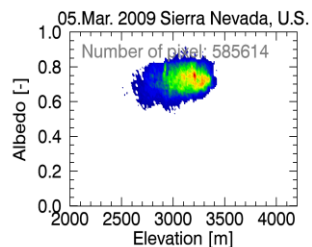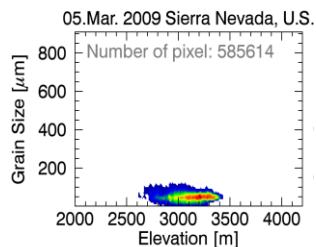
05 Mar 2009
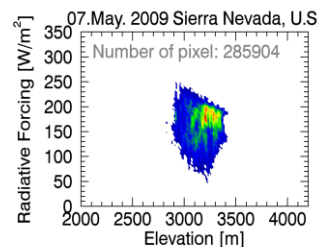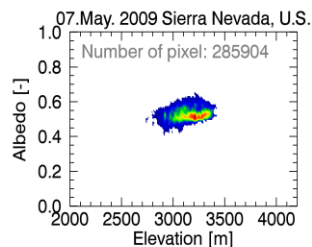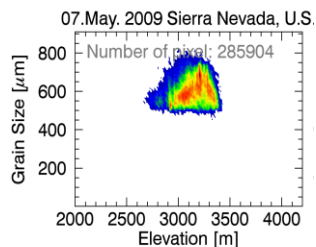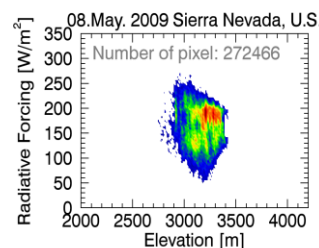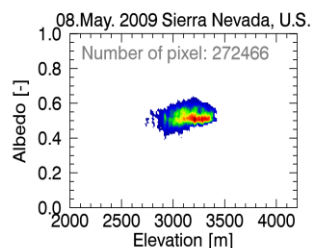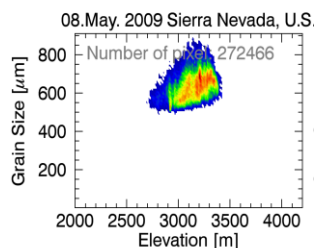
04 Apr 2009

07 May 2009

08 May 2009

Grain Size, Albedo, and Radiative Forcing v.s. Terrain Aspect
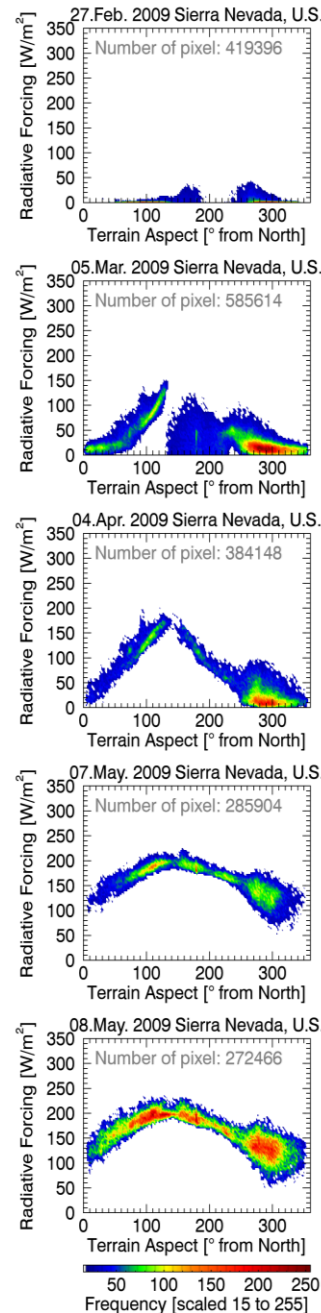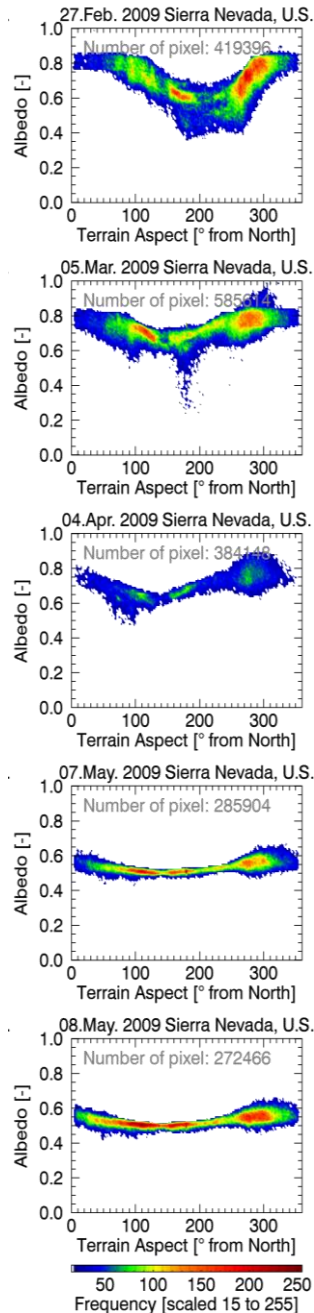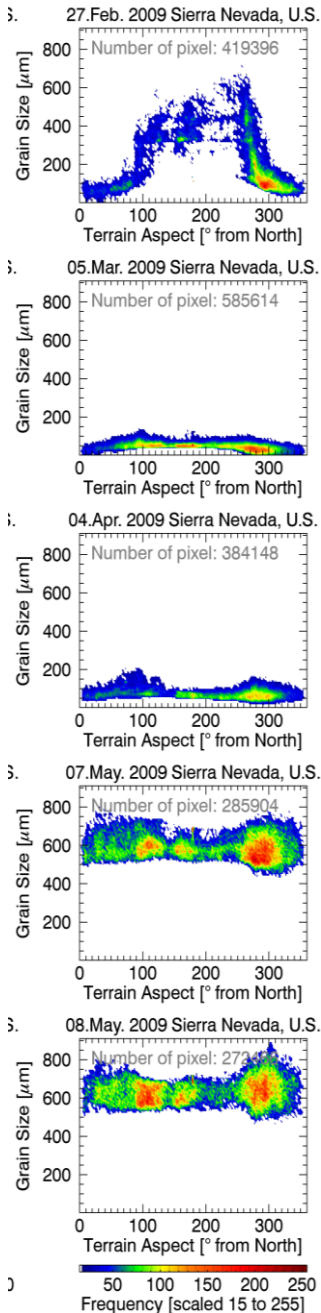

27 Feb 2009

05 Mar 2009

04 Apr 2009

07 May 2009

08 May 2009

Conclusions

- Complex local/regional climate-snow-terrain feedbacks with snow

- ASO and this study are first to show spatially continues snow grain size, albedo, and radiative forcing at multiple time steps during the ablation period thanks to imaging spectroscopy.

- Intuitive results:
  - smaller grain sizes on north facing slopes
  - inverse relationship between grain size and albedo
- New and counterintuitive results:
  - faster grain growth rates at higher elevations
  - higher grain sizes at high elevations during strong melt

- Our methods and algorithms can be applied to e.g. HyspIRI

Thank You!

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